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PERSPECTIVES ON THE USE OF LAND COVER DATA FOR ECOLOGICAL INVESTIGATIONS

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The research of many landscape ecologists is dependent upon spatial data sets developed by scientists, cartographers, and resource analysts. One database that is very important in many ecological investigations is land cover. Land cover databases represent the patterns of natural vegetation, the extent of anthropogenic activity, and some of the potential for future uses of the landscape. Land cover databases; therefore, are essential inputs to studies of the spatial configuration of the landscape and investigations of ecological status, trends, stresses, and relationships.

We are part of a U.S. Geological Survey (USGS) National Land Cover Characterization Program (LCCP) team that is engaged in research leading to the development of land cover databases. Our work spans local to regional to global venues (see, for example, Loveland et al. 1991, Loveland et al. 1999, Vogelmann et al. 1998), and the results of our research and development contribute to a wide range of applications. Because we recognize that the needs for, and applications of, land cover data are constantly evolving, we pay close attention to what researchers in other fields do with the results of our efforts. Monitoring the applications of our land cover data sets is invigorating, but sometimes worrisome. We see exciting and innovative applications of our data that we did not anticipate, but we also see applications that we consider inappropriate, considering the limitations of our source materials, mapping technologies, and expertise. We clearly recognize the strong demand at all scales for land cover data, and we also recognize that we must constantly work toward improvements in data content and quality if our data sets are to meet the diverse needs of scientific users.

While we strive to produce data sets that meet state-of-the-practice standards, we confess that our products are imperfect. This is also true of land cover data sets produced by other organizations. These imperfections, along with the specifications of the land cover products we and others develop, are important to landscape ecologists because the imperfections affect the accuracy, consistency, and credibility of the analyses made when land cover data are used.

Most land cover products are interpreted from remotely sensed data, although some large-scale land cover maps may be based on field mapping. In all cases, land cover data sets are the result of interpretations of observations of landscape conditions. The interpretations are dependent upon the characteristics and quality of the data, the methods used to interpret and map land cover from the data, and the abilities of the interpreters doing the analyses. For an excellent, thought-provoking review of the role of remotely sensed data in landscape ecology, see Frohn's (1998) recent book. For a review of the technical characteristics of remotely sensed data in an ecological context, readers can consult Quattrochi and Pelletier (1990).

One form of remotely sensed data, aerial photography, is typically used to produce large-scale land cover data sets. Air photos are usually interpreted using manual mapping techniques in which a suite of variables visible in the photo, such as color or tone, pattern, texture, size, location, and association, are considered. With satellite imagery such as Landsat and SPOT, computer-assisted techniques are commonly (though not exclusively) used to map land cover. In this case, the relationship between land cover and spectral characteristics is the starting point for determining land cover types. Different satellites collect data in different portions of the electromagnetic spectrum. The suitability of the data for land cover mapping

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depends on the specific spectral region and the number of spectral bands collected by the particular sensor. With either manual or computer-assisted interpretation, the outcomes are the direct result of interpreter decisions and there can be significant variability among interpreters (McGwire 1992). Image interpretation is both an art and a science and there are subjective aspects to the process that can result in inconsistent interpretations. Therefore, understanding the nature of the inconsistencies is important to the wise use of land cover data.

The most obvious measure of land cover mapping quality is classification accuracy. As such, it is essential that all land cover data sets produced for scientific application have accuracy statements (Estes and Mooneyhan, 1994). In the past, accuracy assessments of land cover products were uncommon. Recently, greater emphasis has been placed on this issue. We now develop accuracy statements for all USGS-LCCP products. As realistic accuracy statements are produced, we must collectively define the acceptable accuracy standards that guide decisions regarding the use of a particular data set in an ecological assessment.

We believe that when mapping general land cover for large areas using computer-assisted interpretation of satellite data, overall classification accuracy of approximately 75% should be expected (for example, see Homer et al. 1997, Kroh et al. 1995, Vogelmann et al. 1998). While there are many examples in the remote sensing literature of accuracy at 90% or better, those figures typically represent small-area methodological tests that seldom yield such impressive results when applied over large geographic areas. Perhaps more importantly, accuracy numbers will be directly related to the number of classes. For example, is a two-class map with 95% accuracy better than an eight-class map with 80% accuracy? Consider, also, that the accuracy of land cover maps varies significantly from category to category. For example, consistent differentiation of mixed forests from needleleaf or broadleaf forests is very difficult and confusion among these classes will be common. It is important to think about the "application" accuracy of land cover – or how individual class accuracy affects a specific application. A recent study by Defries (1999) shows how global land cover data with a traditional accuracy of 78% actually has a climate modeling application accuracy over 90% because of the "acceptable" misclassifications (i.e., those that do not affect the derivation of surface roughness or leaf area index parameters) that do not have a negative effect on the parameterization of land-atmosphere interaction models. Thus, information on classification accuracy should be given to enable flexible tailoring for a suite of applications.

People often assume that an accuracy value somehow provides a sort of panacea. In actuality, accuracy values can often give the wrong impression; they are most useful when a user takes the time to consider the implications of all aspects of the accuracy. Basically, landscape ecologists should insist on land cover accuracy statements, but are advised to understand those statements in the context of their particular study. For a good treatment of the impacts of classification accuracy and spatial consistency on landscape metrics, see the work of Wickham et al. (1997).

In addition to accuracy, there are several other characteristics of land cover data that should be considered for application in ecological studies. Some important characteristics are:

SCALE AND MINIMUM MAPPING UNIT (MMU)

These two characteristics are often misunderstood and should be considered in the context of each other. Scale is communicated as the representative fraction between earth and map distance (for example, 1:24,000 means that one unit of measurement on a map equals 24,000 of the same units on the earth). Scale is also a term of confusion between mappers and landscape ecologists because they use the term in opposite ways. Our large-scale (large representative fraction) maps typically provide detailed land cover for small geographic areas. In general, the larger the scale, the more spatial and thematic detail can be represented in the map. Thus, a 1:24,000-scale land cover map will depict smaller occurrences of land cover and more detailed land cover categories than a 1:250,000-scale map.

Minimum mapping units define the smallest land areas represented in a database. As map scale decreases (meaning the information content becomes more general but covers larger geographic areas), the MMU increases. When calculating landscape metrics corresponding to landscape configurations, scale and MMU become important. Generally, smaller scales and larger MMU's result in simpler measures of complexity. We should note that this concept is typically understood in studies in which our land cover data are applied. However, the 1970's vintage land use and land cover data (commonly known as LUDA or Land Use Data Analysis data) produced by the USGS are often applied without consideration of the MMU.

The MMU of this data set varies with land cover category. For example, classes representing human activity have a 10-acre MMU, whereas rural and natural classes have a 40-acre MMU (Anderson et al. 1976). Thus, measures of landscape fragmentation and complexity will be affected by a mapping decision to represent some classes at a finer spatial detail. Interpretation of statistics generated from these data must consider this issue.

A special note about pixels, or picture elements, is necessary. Pixels are the smallest geographic unit in digital satellite images. However, they do not represent the effective MMU in a land cover data set interpreted from digital images. Because of a number of technical issues corresponding to land surface-atmosphere-energy interactions, sensor operation, and image processing methods, the actual MMU is typically greater than the pixel dimensions. For example, our AVHRR land cover data set covering the globe has 1-km pixels, but the smallest resolvable geographic feature is more likely about 4 km by 4 km. Thus, landscape features that are mapped from these data must have a spatial extent of approximately 16 km². So even though we assign land cover attributes to pixels, we rarely interpret land cover at that spatial resolution. Instead, we are primarily concerned with documenting the spatial patterns made by common classes of pixels. Moreover, all pixels are mixed at some spatial or thematic scale. We point to observations made by Quattrochi and Pelletier (1990) that concepts of heterogeneity and homogeneity are scale-dependent because they describe how individual land cover components or processes are interrelated across a landscape. For any given study there is an appropriate scale for analysis that corresponds to the size of the study area, the landscape patterns being investigated, and the maps that capture patterns of land cover.

THEMATIC CONTENT

Land cover maps are typically comprised of categories of land cover and/or land use. Generally, thematic content is based on hierarchical classification schemes such as the USGS Anderson system (Anderson et al. 1976) or the National Vegetation Classification Standard produced by the Federal Geographic Data Committee (1997). Theoretically, scale is closely tied to classification systems, and small-scale maps usually use very general land cover classes. In practice, land cover maps are typically mapped to the most detailed level possible, often varying from class to class so that the resulting map may include categories from all levels of the hierarchy. Thus, some maps have inconsistent thematic detail – which translates to variable spatial complexity. As with variable MMU's, this will introduce bias in measurements of landscape complexity.

DATA SOURCES AND STRUCTURE

Land cover maps derived from remote sensing are developed from either raster images or photos. Interpretation from photos produces smooth, clean lines, with the amount of detail of the land cover polygons determined by the interpreter. Two interpreters working on adjacent areas may use different decision rules regarding line generalization. Land cover maps classified using digital remotely sensed imagery have mapping units defined by statistical criteria and can therefore be developed more consistently. However, because of ambiguities between spectral data and land cover, digital classifications are inherently noisy, with jagged-edge map regions and "salt-and-pepper" pixel patterns. Although the results look complex, the complexity may be an artifact of the mapping techniques. Comparison of landscape metrics derived from land cover maps developed from analog versus digital sources, captured as lines or vectors versus pixels, is problematic.

TEMPORAL REPRESENTATION

All land cover data are specific to a particular time that corresponds to the dates the source data were collected. For local-area studies, remotely sensed data typically represent a specific date. However, as the area mapped becomes larger, the time period of the source imagery becomes broader because more time is required for overpasses of aircraft or satellites and cloud-free conditions may be more difficult to achieve. In some cases, a time span of several years may be required to compile a relatively cloud-free data set. During this time, changes in land cover can occur. For example, our 1-km global land cover characteristics database was interpreted from satellite data collected over a 12-month period (Loveland et al. 1999), whereas our 30-m U.S. land cover data set is based on satellite images collected over three years

(Vogelmann et al. 1998). The differences in phenological conditions may result in land cover databases with internal inconsistencies. Currently, this problem is unavoidable, but it should be considered when interpreting landscape metrics.

Basically, there are no perfect data. Therefore, it is important to understand the strengths and weaknesses of the land cover data that you are considering for your study. While land cover databases have inaccuracies and inconsistencies, valuable analysis can still ensue from their use. Applying caution and careful interpretation to analytical results will lead to sound scientific statements.

CONCLUSION

We hope this discussion of the limitations of land cover data leads to improved application of land cover data sets. Equally important is our hope that we can engage in an ongoing dialog with landscape ecologists regarding land cover data strengths and weaknesses, and can work together to develop more useful and innovative land cover databases in the future. As we look to the future, we see some important trends in land cover programs that will affect the land cover databases available for scientific applications. Key trends include increases in:

- Available land cover data. The USGS LCCP will continue producing national and global land cover databases on both an operational and experimental basis. The USGS Gap Analysis Program will also continue to provide detailed vegetation data sets for the nation on a cyclic basis (Scott et al. 1993). International programs, such as the Global Observation of Forest Cover of the Committee for Earth Observation Satellites will work toward improvements in land cover data needed for environmental treaty compliance (Ahern et al. 1998).
- Quantitative attributes of land cover, including tree canopy density, leaf area index, and other physiognomic variables.
- Dimensionality of land cover products, including multi-resolution, multi-attribute (i.e., different land cover legends, physiognomic variables, floristic descriptions), and multi-temporal (i.e., phenology) elements. The added dimensions should improve the utility of land cover products for specific applications.
- Emphasis on the use of appropriate metadata standards that provide the necessary evidence of data quality and heritage. Included in this are accuracy statements.

A variety of factors, including improvements in computing capabilities, acceptance of geographic information systems as analytical tools, and advancements in integrated environmental modeling and assessments, are combining to provide the impetus for innovation and expansion in operational land cover characterization programs. For these programs to be successful, ongoing dialog and collaboration is crucial.

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